Supervisor: Yuxiao.Fang
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The Investigation of Synaptic Devices Based on Carbon Nanotubes (CNT)

----For Image Edge Recognition

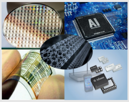
Team member：Shengda Gao, Jiadong.Shen, Herong.Sheng, Junyi.Lin, Xiang.zhou, Shuchang Zhang,

01 Abstract

Our project successfully developed carbon nanotube (CNT) synaptic transistors with optoelectronic synergistic stimulation capabilities, enabling edge detection and enhanced recognition through peripheral circuits. Additionally, we integrated these devices with convolutional neural networks (CNNs) and reservoir computing algorithms to achieve efficient recognition of handwritten characters and clothing items, demonstrating their potential in intelligent sensing and image processing.

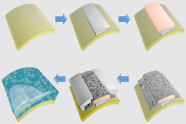
02 Introduction

Conventional image sensors struggle with accurate edge detection in low-contrast or complex environments due to their static optoelectronic processing. Our project addresses these limitations by utilizing carbon nanotube (CNT)-based synaptic devices, which offer exceptional electrical conductivity, high surface area, and excellent photoresponse. These properties make CNTs ideal for dynamic and adaptive optoelectronic applications. Furthermore, we aim to enhance edge detection capabilities by integrating these CNT synaptic transistors with advanced peripheral circuits. This combination enables efficient and robust recognition of tasks like handwritten character and fabric identification, even in challenging visual scenarios.

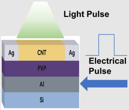


The potential application of carbon nanotubes (CNT)

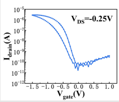
03 Device Results



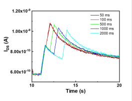
TFT fabrication process



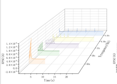
Cross section of TFT



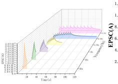
TFT transfer curve



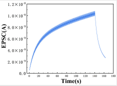
Paired Pulse Facilitation (PPF)



Frequency response under electrical stimulation (0~-0.5 V, 200 ms)



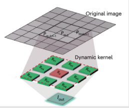
Frequency response under light stimulation (520 nm, 10 mW, 200 ms)



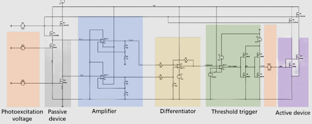
Weight update curve of synaptic device

04 Peripheral Circuit of Edge Recognition

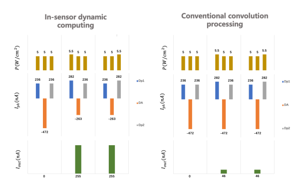
The edge enhancement circuit is designed with a combination of active and passive optoelectronic devices. The passive devices detect local light intensities, while the central active device dynamically adjusts its response based on signals from the surrounding devices. This configuration allows the circuit to selectively amplify small differences in light intensity, enhancing edge detection in real-time. The design enables precise identification of edges, making it ideal for applications in complex visual environments.



Device array for edge detecting

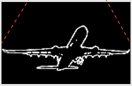


Circuit diagram of in-sensor dynamic computing



Measured photocurrent of each device for different combinations of light intensity illuminating the three devices, together with the corresponding total photocurrent output of the passive devices and the active device (Iout = ∑Iph-Pi + Iph-A)

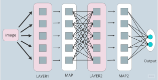
Original image



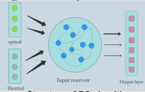
Processed image

05 Neuromorphic Application

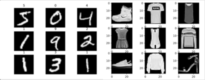
With the edge enhancement circuit in place, we integrated it with Convolutional Neural Networks (CNN) and Reservoir Computing (RC) algorithms. By leveraging the conductance changes of the synaptic devices, we dynamically updated the network weights, achieving efficient recognition of handwritten digits and fashion items. This approach resulted in a maximum recognition accuracy of 87%.



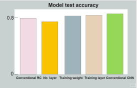
Structure of CNN algorithm



Structure of RC algorithm



Recognition results of minist database



Recognition accuracy of different networks

06 Conclusion

Our approach combines CNT-based synaptic devices with advanced edge enhancement circuits and intelligent algorithms, demonstrating a powerful solution for complex visual recognition tasks. The integration with CNN and RC algorithms leverages dynamic weight updates based on conductance changes, achieving high recognition accuracy of up to 87%. This innovation showcases the potential of our design in enhancing intelligent vision systems for various real-world applications.